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New estimates and complications in the assessment of female functional maturity for the European lobster (*Homarus gammarus*) on the Yorkshire Coast (UK)

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Abstract
New estimates of female *Homarus gammarus* functional maturity were developed from targeted offshore and quayside based industry surveys in the Yorkshire Coast fishery. Offshore surveys also provided the first stock specific quantification of pre-recruit contributions. A contrast in results identified a new complication in estimating functional maturity attributed to 'soft' animal exploitation which is reviewed and assessed.

Keywords: *Homarus gammarus*; functional maturity; Yorkshire Coast

1 | INTRODUCTION

Determining when individuals attain sexual maturity is a fundamental consideration when assessing a stock's sustainability, where inaccurate estimates can have far reaching consequences on a population and its management (Free *et al.* 1992; Tully *et al.* 2001; Laurans *et al.* 2009). For the European lobster, *Homarus gammarus* (Linnaeus 1758) multiple and varied approaches have been used to assess when females achieve sexual maturity, characterised through physiological, morphological and functional indicators (Free *et al.* 1992; Tully *et al.* 2001; Lizarrago-Cubedo *et al.* 2003). The most common approach has been the assessment of functional maturity through the direct observation of the ovigerous condition (egg bearing), which has been utilised in multiple stock assessments and provided supporting evidence to justify an increase in the European minimum landing size (MLS) from 85 mm to 87 mm carapace length in 2002 (Free *et al.* 1992; Tully *et al.* 2001; Lizarrago-Cubedo *et al.* 2003; Laurans *et al.* 2009; Smith 2010). However maturity assessments derived from external indicators have noted limitations due to their reliance on visual observations, for example the seasonal presence of egg clutches, which can lead to overly conservative estimates (Free *et al.* 1992; Tully *et al.* 2001; Laurans *et al.* 2009). This communication provides new estimates of female functional maturity, derived from sampling industry catches offshore at the point of capture and quayside landings from the Yorkshire Coast *H. gammarus* fishery (North-East UK). Furthermore the impact of newly moulted, post-ecdysis animal exploitation referred to as 'soft' hereafter, for simplicity and its impact on functional maturity estimates are considered.

Homarus gammarus' reproduction and growth is facilitated through periodic ecdysis with moult timing attributed to behavioural and environmental drivers (Schmalenbach 2009). As a generalisation, mature individuals ecdysis intervals are surmised to be annual or biennial, with environmental conditions, in particular water temperature, identified as significant regulating factors (Nicosia and Lavalli 1999; Agnalt *et al.* 2006). In consideration of reproductive behaviours for mature individuals, it is assumed that in a similar manner to *Homarus americanus*, *H. gammarus* females approaching ecdysis select a mate following the assessment of male size compatibility and resources (Bushmann and Atema 1997; Skog 2009). During a period of co-habitation, the male protects the female both prior and post ecdysis during which copulation occurs. Eggs are fertilised, transported through oviducts then secreted from gonopores onto the pleopods setae, at which point they become externally visible (Nagaraju 2011; Erkan and Ayun 2014). Hardening of the new exoskeleton is facilitated through calcium bio-mineralisation, a process which can take several weeks and is dependent on animal size, influenced by environmental conditions, food availability and can be aided by consumption of their discarded exoskeleton (Schmalenbach 2009).

2 | METHODOLOGY

To assess female functional maturity in the Yorkshire Coast stock, two sampling approaches were taken;

i. Offshore surveyors accompanied commercial fishing vessels during April to October 2008 – 2009, operating in the Yorkshire Coast inshore pot fishery (within 12 nautical miles; Northern Boundary grid reference NZ77832 19139; Southern Boundary TA39810 10430). The Yorkshire Coast fleet are predominantly dedicated potting vessels, operating in inshore waters within 30 miles of their home ports. All commercial survey vessels worked UK style 36–42” parlour pots with either single or double parlours which are left to soak for 24–48 hours during the main fishing season. Vessel effort ranged from 300–800 pots per day dependent on vessel size and time of year. Surveys were undertaken in a stratified manner, with trips scheduled on a monthly basis within 5 nominal survey areas. The survey areas were designed to be a similar size, encompassing the entire Yorkshire Coast fishery (Staithes to Spurn Point) and were developed in consultation with commercial operators based on their main fishing grounds. During each survey, the abundance of *H. gammarus* was recorded from each of the first 20 pots over 3 random survey fleets (or multiple of). All individuals were retained for biometric assessment with sex, carapace length (CL; mm), presence of eggs and egg stage recorded, capturing details from 2,437 females including 310 ovigerous animals.

ii. Quayside sampling was targeted on a monthly basis during April to October 2012 – 2013 at the key ports of Bridlington (TA 18357 66694), Scarborough (TA 04018 88713) and Whitby (NZ 89730 11329). Sampling was undertaken as commercial vessels unloaded their catch to the quayside where fishermen provided surveyors with 50kg standard fish boxes of catch on request. Biometrics where recorded from a minimum of 150 animals per port visit, comprising of 50 animals from 3 separate vessels which were randomly selected. Biometrics where captured from 4,239 female recruits including 1,023 ovigerous animals.

Inclement weather and vessel availability impacted all survey years, therefore data was pooled for each sampling method and time series, then developed into separate maturity assessment models, nominally; Model 1-offshore and Model 2 – quayside with all analysis undertaken in the R (R Development Core Team 2011). The pre-recruit (<87 mm CL) data captured from the offshore sampling (Model 1) was also utilised in Model 2, as quayside sampling only provided biometric information from recruit animals.

For *H. gammarus* the size at which 50% of a cohort attains sexual maturity is regarded as an appropriate reference point (FB^{50}) for maintaining a brood stock with sufficient capacity to ensure sustainable egg production (Free *et al.* 1992; Caddy and Mahon 1995; Agnalt *et al.* 2006; Laurans *et al.* 2009). Sexual onset of maturity estimates (SOM) were developed for the two models following the generalised logistic model outlined by King (1995) where the proportional relationship between total female and ovigerous abundance was assessed at 2 mm CL increments modelled as;

$$P = 1 / (1 + \exp[-r(L - Lm)])$$

where r is the slope of the curve and Lm represents FB^{50}.

3 | RESULTS AND DISCUSSION

An adjusted proportion of 75% was used in both models, based upon the maximum proportion of ovigerous animals observed in any size class, in this case derived from quayside data (King 1995). FB^{50} was estimated between 100.17±8.53 mm (Model 1- offshore; Mean ±SD/SE) and 92.59±3.97 mm (Model 2 - quayside; Figure 1a and 1b). FB^{95} was estimated between 131.38±25.92 mm (Model 1-offshore) and 113.57±9.54 mm (Model 2 - quayside; Figure 1a and 1b). Hosmer–Lemeshow tests (Model 1: χ^2 = 0.304, $p > 0.05$ and Model 2: χ^2 = 0.163, $p > 0.05$) indicated that the proportion of functionally mature individuals did not differ significantly from the model predictions and the overall fit of both models was good. The results for FB^{50} broadly support median estimates of female maturity which range from 79–110 mm as reviewed by Smith (2010), with quayside results (Model 2) closely aligning with a previous estimate for the stock of 90 mm (Free *et al.* 1992).

In review of Model 1 (offshore), a significant decline in the proportion mature was apparent following the MLS size class, where an approximate 50% decline was identified following the 87–88 mm (32%) to 89–90 mm (29%) and 91–92 mm (17%) size classes, with the proportions in subsequent classes also appearing depressed (Figure 1a). Provisional analysis of this dataset during 2010 and the identification of this decline at the MLS adjunction led to the commission of the complementary quayside surveys in 2012 and 2013. As a significant decrease in the proportion mature following the MLS was considered a questionable departure from previous maturity estimates and indicative of a sampling artefact associated with exploitation (Free *et al.* 1992; Laurans *et al.* 2009). Model 2 (quayside) did not indicate a decline at the MLS adjunction, with the combined pre-recruit and recruit data offering a better model fit, with more concise confidence intervals (Figure 1b).

In consideration of female *H. gammarus*' reproductive physiology and factors influencing the fishery, it appears that during offshore surveys commercial operators were capturing and retaining female animals whilst 'soft', following growth or recruitment into the commercial fishery, but prior to extruding their eggs and being classified as ovigerous by surveyors. Notably during this study several commercial vessels retained and landed large volumes of 'soft' animals, segregated from their main catch for private or independent sale. In contrast the majority of quayside landings to merchants have self-imposed restrictions on animal hardness, with 'soft' individuals rejected due to poor quality meat-yield and high water content, assessed through a squeeze test of the carapace (Pers. Observation). It appears that this self-regulation of quality affords sufficient time for mature females who have successfully mated to extrude their eggs. This contrast in 'soft' animal exploitation accounts for the underrepresentation of ovigerous animals in the solely the recruit size classes and the difference between sampling strategy datasets. Therefore questions must be asked over the appropriateness of using the visual observation of the ovigerous condition as a proxy for functional maturity. Potentially this offshore sampling limitation could be mitigated through the inclusion of a measure of animal hardness, with 'soft' animals excluded from maturity assessments, or a temporal sampling restriction during the peak ecdysis period (July to September in this fishery), however this would significantly impact sample numbers and sampling opportunities. In light of this studies results it would appear more appropriate to recommend that fisheries managers estimate *H. gammarus* recruit maturity from targeted quayside sampling, which captured samples from a wide range of vessels, was more cost effective and encompassed a more comprehensive distribution of size classes.

In consideration of the wider impacts of soft animal exploitation, it may have influenced previous assessments of functional maturity using estimates derived from offshore sampling, generating highly conservative maturity estimates. Furthermore other crustacean species with a similar reproductive physiology may be subject to similar limitations and this should be considered when designing sampling methodologies.

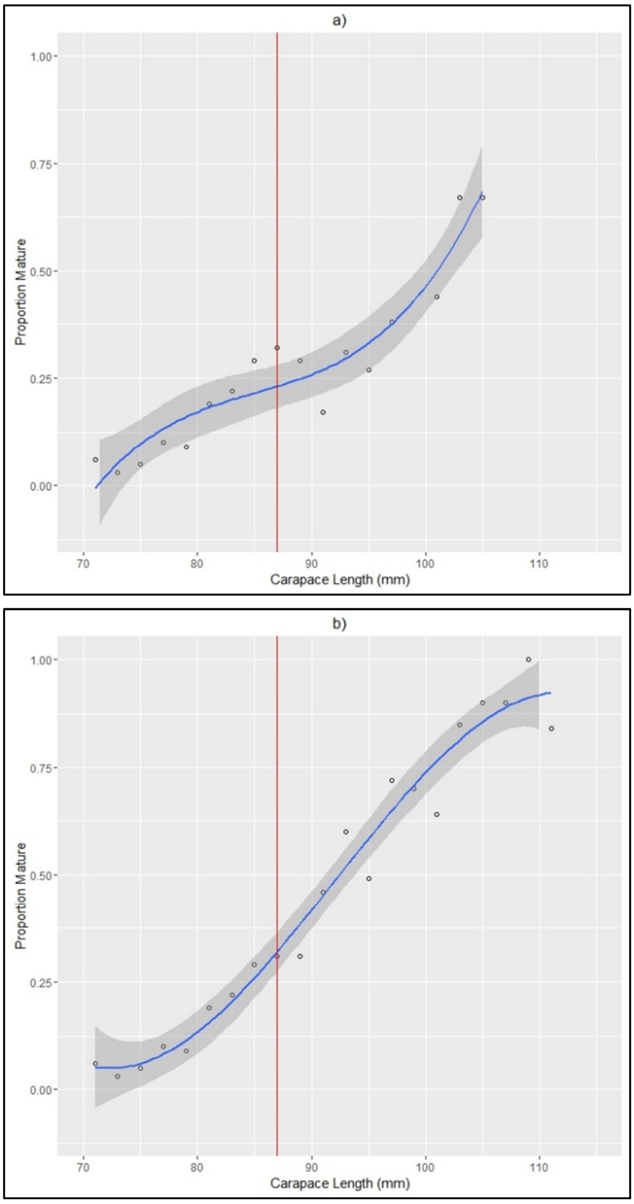

FIGURE 1 ***a)*** Sexual onset of maturity model estimates (blue line) based on offshore surveys from 2008–2009, with 95% confidence intervals (grey shading) and the European MLS denoted by (vertical red line). ***b)*** Sexual onset of maturity model estimates (blue line) based on offshore surveys pre-recruit data from 2008–2009 and quayside recruit data from 2012–2013, with 95% confidence intervals (grey shading) and the European MLS denoted by (vertical red line).

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